UTILITIES DIVISION
Water Resources

Water Resource Sustainability Study
for the City of Flagstaff, Arizona
- Overview -

Introduction

Economic vitality and community sustainability start with a reliable, long-term water supply. The purpose of this study is to provide the City of Flagstaff and its decision makers an evaluation of its water supplies and their long-term sustainability and reliability for citizens here today and future generations. More simply put, the purpose of the study is to determine "*what is Flagstaff's bucket of water that it can objectively rely upon over the next 100-years?"*

The criteria used to evaluate the sustainability and reliability of Flagstaff's surface water, groundwater and reclaimed water supplies will be two fold. First, this study will attempt to identify what is the "sustainable yield" of groundwater pumping within the City's well fields. The second criteria will be to evaluate the city's water supplies against those criteria identified in the Arizona Department of Water Resources (ADWR) Adequate Water Supply program including its proposed revisions and Hydrologic Guidelines.

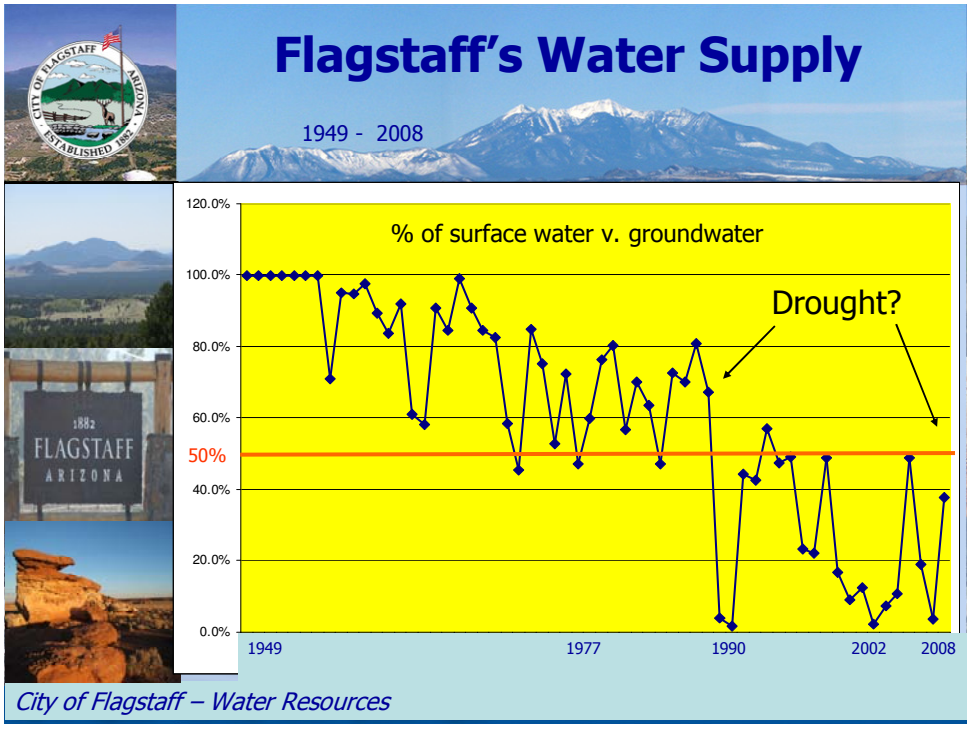
In order to better understand and predict the reliability of local groundwater supplies, a major aspect of this study will be to construct a numerical groundwater flow computer model of the Coconino Plateau aquifers in and around the City of Flagstaff. This tool will be based upon the U.S. Geological Survey's regional northern Arizona groundwater flow model and will be used to determine the physical availability of groundwater in and around Flagstaff over the next 100-years. The results of this study should help the City and its decision makers develop and implement sound water management programs and policies.

Background

The City of Flagstaff has been importing water supplies from outside its incorporated limits for over 100 years dating back to the 1890s. The City's first reliable water supply was surface water from the Inner Basin located 12 miles away within the San Francisco Peaks. In the early 1900s, the City constructed lower Lake Mary Dam over six miles away in order to take advantage of additional surface water within the Walnut Creek watershed. Upper Lake Mary

Dam was completed in the mid-1940s to expand the storage capacity of surface water. During the 1950s, impacts from drought required the City to look for a more reliable water supply in the Woody Mountain area over five miles west of town. In the 1960s, the City continued to expand its groundwater supply by developing a well field adjacent to Lower Lake Mary. The mid-1980s saw the City's first direct use of reclaimed water at the Continental Country Club. Since the late 1990s, numerous additional water supply wells have been developed within and adjacent to the City limits. Lastly, the City continues to expand its direct use of reclaimed water with the construction of the Rio de Flag water reclamation facility in 1993 and the upgrade to the Wildcat Hill wastewater treatment plant completed in 2009.

The City has kept meticulous water production records for many decades. The figure below illustrates the relationship between the use of surface water compared to groundwater over the past 60 years. While the City started out predominantly utilizing surface water, over the past 20 years groundwater has played a more significant role in the City's water resources. During the same time period groundwater levels in certain water supply wells began to experience declines ranging from less than one foot per year to over 13 feet per year.



Previous Work

There have been significant geologic, hydrologic and engineering studies conducted on the Coconino Plateau over the past 50-years by the City of Flagstaff, U.S. Geological Survey, Northern Arizona University and the U.S. Bureau of Reclamation among others. These studies attempted to quantify surface water and groundwater supplies on the Coconino Plateau and all of these historical documents and data will be utilized in this study.

Surface Water

This study will quantify the surface water that has been relied upon in the past 100 years from the Lake Mary watershed and the Inner Basin using historical records. Secondary dry creeks or washes that traverse in and around the City of Flagstaff (e.g., Rio de Flag, Clay Avenue Wash and Pumphouse Wash) may be an important component of localized recharge and this study will attempt to quantify how much they contribute to the groundwater system. Based upon these historical records, this study will attempt to determine the statistical volume of surface water that could potentially be relied upon over the next 100 years.

Groundwater

This study will attempt to determine the volume of groundwater that can be relied upon over the next 100 years using the two criteria discussed earlier; sustainable yield of groundwater pumping and ADWR Adequate Water Supply program. This analysis will include two primary components; first developing a hydrogeologic conceptual model and then a historical groundwater budget for the Flagstaff area.

I. Hydrogeologic Conceptual Model - The development of a hydrogeologic conceptual model will utilize all of the existing data previously mentioned in order to define the regional subsurface geology and hydrology as it pertains to the Coconino (C) and underlying Redwall-Muav (R) Aquifers within the Flagstaff area. The following information will be used when analyzing data and developing the hydrogeologic conceptual model and these data will help in the calibration of the numerical groundwater flow model:

Water Levels – this study will utilize water level information from wells completed in both the C and R-Aquifers where available. Ideally, the data should represent both pre-development (prior to 1950s) and transient conditions (1950s to 2009) as well as identifying historical trends in water level changes with time.

Aquifer Thickness - geologic and hydrostratagraphic unit isopach maps for the C and R-Aquifers will be developed that reflect the historic and current thickness of the aquifers. Additionally, primary structural geologic features (e.g., faults) will be included to illustrate their impact, if any, on the groundwater system.

Aquifer Hydraulic Properties - this study will utilize the results of numerous aquifer pumping tests from the City's water supply wells and from other local water providers that have occurred over the past several decades. The purpose of this analysis will be to develop initial estimates of aquifer hydraulic properties including transmissivity, hydraulic conductivity and storage within the C and R-Aquifers.

II. Groundwater Budget - The purpose of developing a groundwater budget is to quantify the historical components of inflow and outflow of the regional groundwater system. This information will be used to help calibrate the numerical groundwater flow model. The components of the budget will include the following:

Aquifer recharge (inflow) – this study will attempt to estimate the historical annual volume of water that has recharged the C-Aquifer in the Flagstaff area from precipitation as snow and rainfall. Understanding the areal distribution of the recharge and infiltration rates is also important and will attempt to be correlated with the type of geology units at land surface. Other components of recharge include leakage from Upper Lake Mary; infiltration from reclaimed water discharge to the Rio de Flag by the City; reclaimed water disposal from Flagstaff Ranch and Forest Highlands; localized stream flow within the Rio de Flag, Clay Avenue Wash and known limestone sink holes such as the "Bottom-less Pits" near Continental Country Club.

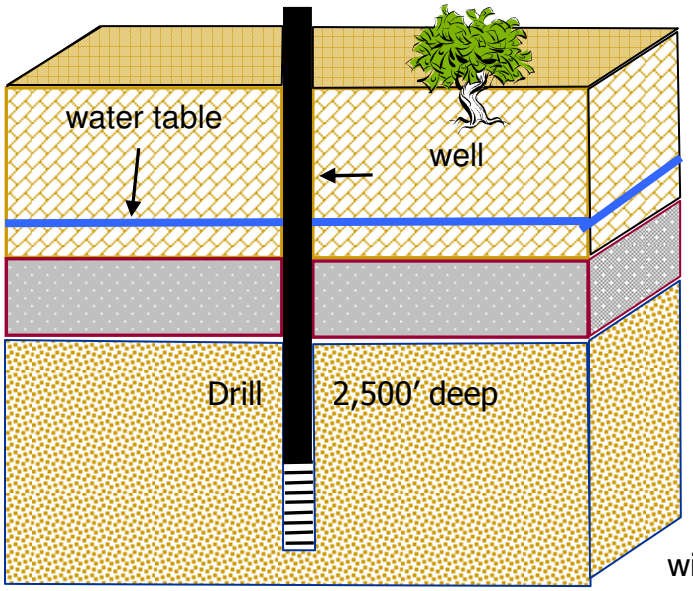
Aquifer discharge (outflow) - There are several ways groundwater exits the Coconino Plateau in the vicinity of Flagstaff which includes groundwater pumping, spring discharge and downward migration from the C-Aquifer to the R-Aquifer. Groundwater pumping is the most significant anthropogenic outflow from the groundwater system and detailed records will be used from the City, Arizona Department of Water Resources, U.S.Geological Survey and local water providers. This study will also attempt to summarize the known spring flows along the Mogollon Rim as well as attempt to estimate the downward movement of groundwater from the C to R-Aquifer, if possible.

Reclaimed Water

The City of Flagstaff's two water reclamation plants produce Class A+ reclaimed water for direct use and groundwater recharge. This study will develop estimates of future wastewater production and subsequent reclaimed water availability based upon remaining undeveloped lands within the City of Flagstaff. Historical estimates of recharge along Rio de Flag will be summarized in addition to projecting how much reclaimed water is expected to be recharged in the future.

Groundwater Physical Availability Analysis

Coconino Aquifer - *conceptualized*



Based upon the information collected and analyzed above, this study will develop a localized numerical groundwater flow computer model of the Flagstaff area that will be based upon the U.S. Geological Survey's regional northern Arizona model. The localized computer model will be constructed using the industry standard software MODFLOW and will be constructed in accordance with sound modeling practices as documented by the U.S. Geological Survey, academia and the ASTM International Standards. The components of the model development will include the following:

Conceptual Model - The numerical model will be constructed based upon the hydrogeologic conceptual model identified earlier. The finalized pre-development and current conceptual groundwater budgets will be used as calibration targets for the model's simulated water balance that relates to model-wide recharge, discharge and change in aquifer storage

Model Domain – The localized model will be a telescopic refinement and imbedded within the boundaries of the larger scale U.S. Geological Survey regional model. The domain will include a broad enough area to incorporate all of the City's existing and potential future water resources.

Model Grid – The model grid cell dimensions and time-step descritization will be based upon the spatial distribution of available data balanced against the

ability to achieve the desired objectives of this study. It is anticipated the model cell dimensions will range from ¼ sq. mile to 1 sq. mile in size.

Model Layers - The localized model will be constructed with a number of layers to adequately simulate the hydrostratigraphic layers within the Flagstaff area of the Coconino Plateau. It is assumed that the model will be constructed with a minimum of three (3) model layers equating to the Coconino Aquifer, confining Lower Supai and the underlying Redwall – Muav Aquifer.

Model Input Parameters – Input parameters that define the aquifer's hydraulic characteristics include hydraulic conductivity, specific storage and porosity. Additional model input parameters include stream flow, recharge from precipitation, groundwater withdrawals and initial distribution (pre-development) and current distribution of groundwater elevations. All of these input parameters for each model layer will be selected based upon the investigative work conducted previously.

Calibration - The localized model will need to be calibrated for pre-development (steady-state) and current (transient) conditions which typically consists of comparing actual versus simulated groundwater levels, estimated versus simulated groundwater budgets, etc. Calibration is an important step in model development since it will yield a more robust tool for predictive simulations. The study will use specific criteria to determine whether the model is adequately calibrated such as Root Mean Error, Mean Absolute Error and Mean Error of measured versus simulated model inputs.

Capture Zone Analysis–Particle tracking - The study will also conduct capture zone analyses of the City's water production wells, well fields and springs. The purpose of this will be to help delineate 3-dimensionally where the groundwater comes from that is withdrawn by each well, well field or discharge to a spring. This is important to help understand the relationship between long-term groundwater availability, recharge and potential impacts to springs relative to the location of a well or well field.

Sensitivity Analysis - The purpose of conducting this analysis is to quantify the uncertainty in the results of the calibrated model that is caused by the uncertainty in the understanding of the model's input parameters. Typically, uncertainty in a model input parameter such as hydraulic conductivity, porosity or recharge is compared against the results of the calibrated model. This type of analysis is critical in understanding the calibrated model's limitations and usefulness for predictive analysis.

Future Predictive Scenarios - In order to predict the long-term availability of groundwater supplies that the City of Flagstaff may rely upon over the next 100-years, this study will simulate four groundwater availability scenarios using the localized numerical groundwater flow model. The four (4) scenarios to be simulated are: 1) what are the hydrologic impacts if the City continues to use its water supplies the way it has historically over the next 100 years?; 2) what are the hydrologic impacts if the current 12-15 year drought were to continue and surface water is available only upon a limited basis or not at all over the next 100 years (i.e., a dry year scenario)?; 3) what are the hydrologic impacts if long-term climatic conditions return and surface water is available at historical norms (a wet

year scenario)?; and 4) what are the hydrologic impacts if the City were to hold groundwater pumping to a determined "sustainable yield" level and the remaining water needs will be met by an imported water supply (e.g., Red Gap Ranch or the Colorado River)?

All scenarios will include two separate growth predictions, one that is based upon the remaining undeveloped land identified within the voter approved 2001 Regional Land Use and Transportation Plan as well as projected growth in adjacent areas such as Doney Park, Kachina Village, Bellemont, etc. The second growth prediction will include a more intensified land use within the City based upon the work currently being undertaken for the 2012 update to the Regional Land Use and Transportation Plan.

Conclusions – 100-year Sustainable Water Resources

The final results of this study will be to provide a range of estimates of groundwater, surface water and reclaimed water that could potentially make up *Flagstaff's bucket of water that it can objectively rely upon over the next 100-years.* The conclusions of this study should provide a rational scientific basis and recommendation towards the development and implementation of sound municipal water management programs and policies.

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